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Combination of the LEP2 $f\bar{f}$ Results

LEPEWWG $f\bar{f}$ Subgroup

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Abstract

Procedures for the averaging of the LEP2 $e^+e^- \rightarrow f\bar{f}$ cross section and forward-backward asymmetry results are discussed as are the common systematic uncertainties between the experiments. A preliminary combination of the results for the 1999 Summer Conferences is made.

1 Introduction

LEP has operated at energies well above the Z-pole since Autumn 1995. During this time data have been collected at centre-of-mass energies of 130.2 and 136.2 GeV (in 1995 and 1997), 161.3 and 172.1 GeV (in 1996), 182.7 GeV (in 1997) and 188.6 GeV (in 1998). In addition, during 1999 LEP is running at energies of 192 and 196 GeV. In this note we consider the combination of the LEP results on $e^+e^- \rightarrow f\bar{f}$.

At the Z-pole the data from the four LEP experiments has been combined at the level of pseudo-observables [1]. This procedure is no longer appropriate at energies well above the Z-pole. Instead we combine directly the measured data in terms of cross sections (for $q\bar{q}$, $\mu^+\mu^-$ and $\tau^+\tau^-$ final states) and forward-backward asymmetries (for $\mu^+\mu^-$ and $\tau^+\tau^-$ final states). In this first attempt at such a combination, the e^+e^- final state is not considered, due to the complication of the t-channel effects. Nor are measurements for specific quark flavour final states combined. Only data corresponding to non-radiative event samples are treated. Furthermore, the combination is made only for the 183 and 189 GeV datasets as these have the highest luminosities and centre-of-mass energies.

Various considerations arising in defining common experimental conditions are discussed in Section 2. The kind of input data provided by each experiment is presented in Section 3. This section also addresses the question of common systematic uncertainties. Section 4 describes the method used to average the results. Section 5 presents these preliminary combined results and compares them with SM predictions. In Section 6 the averaged results are used to place limits on four-fermion contact interactions between leptons. Some conclusions and thoughts about the direction of future work are given in Section 7.

2 Definition of the $f\bar{f}$ Signal

Because of the much increased importance of radiative processes in $e^+e^- \rightarrow f\bar{f}$ at LEP2 energies compared to LEP1, in particular radiative returns to the Z, there are some subtleties which need to be considered when averaging the results. The reduced centre-of-mass energy $\sqrt{s'}$ can be defined in several ways. For example, it can be defined as the invariant mass of the s-channel propagator or as the bare invariant mass of the outgoing $f\bar{f}$ pair. The correspondence between the experimentally measured and the theoretical definitions of s' is not straightforward: FSR cannot be cleanly separated from ISR since ISR-FSR photon interference is important, unlike at LEP1. For $q\bar{q}$ final states, there exists the possibility of gluon radiation before the emission of an FSR photon. This makes is difficult to define the bare $q\bar{q}$ invariant mass. In addition, FSR photons cannot, in general, be clearly distinguished experimentally from photons from quark-jet fragmentation. Different experiments have adopted different procedures in the experimental estimation and theoretical definition of s'.

A further complication is that the experimental efficiency drops to zero at small polar angles, particularly for leptonic final states. Some experiments rely on theoretical calculations to extrapolate their measurements to the full 4π angular acceptance, whereas others prefer to quote their results inside a limited acceptance. The SM predictions at small polar angles are particularly influenced by ISR-FSR photon interference, which was until very recently a source of theoretical uncertainty as it was only known to lowest order.

Before averaging the results, it is first necessary to choose a common definition of the $\mathrm{f\bar{f}}$ signal and correct the results of the four experiments to this common definition. In future, thanks to the on-going research of the LEP2 Monte Carlo Workshop [6], it should become clear which is the best choice for this definition. However, this is not yet the case. Therefore, all averages presented in this note are obtained using two alternatives for the common signal definition:

- **Definition 1:** $\sqrt{s'}$ is taken to be the mass of the s-channel propagator, with the $\mathrm{f\bar{f}}$ signal being defined by the cut $\sqrt{s'/s} > 0.85$. ISR-FSR photon interference is subtracted to render the propagator mass unambiguous.
- **Definition 2:** For dilepton events, $\sqrt{s'}$ is taken to be the bare invariant mass of outgoing difermion pair. For hadronic events, it is taken to be the mass of the s-channel propagator. In both cases, ISR-FSR photon interference is included and the signal is defined by the cut $\sqrt{s'/s} > 0.85$. When calculating the contribution to the hadronic cross section due to ISR-FSR interference, since the propagator mass is ill-defined, it is replaced by the bare $\mathrm{q\bar{q}}$ mass.

For both definitions, results are presented inside the full 4π angular acceptance. Events containing additional fermion pairs from radiative processes are considered to be signal, providing that the primary pair passes the cut on $\sqrt{s'/s}$ and that the secondary pair has a mass below 70 GeV/c^2. The signal definitions used by the individual experiments can be found in the Appendix. Definition 1 corresponds to that used by L3 and OPAL, whereas Definition 2 represents a compromise between those of ALEPH and DELPHI.

3 Input Data

In order to make the combination, each experiment provided card files containing their measurements of the $\mathrm{q\bar{q}}$, $\mu^+\mu^-$ and $\tau^+\tau^-$ cross sections and of the $\mu^+\mu^-$ and $\tau^+\tau^-$ asymmetries at 183 and 189 GeV. These card files are given in the Appendix. The results given by the experiments are based on numbers in their publications [7], although some applied small corrections to these.

Each experiment's results correspond to their own choice of the $\mathrm{f\bar{f}}$ signal definition. To facilitate the correction of the results to the common choice of definition used for the average, the experiments therefore also provided the SM prediction corresponding to each of their measurements. These predictions were obtained using the semi-analytical program ZFITTER v6.04 [2] and can be found in the Appendix.

The total uncertainty on each measurement is broken down into five subcomponents, again given in the Appendix. For the results of final state X from experiment Y at a particular centre-of-mass energy, these are:

1) The statistical uncertainty plus uncorrelated systematic uncertainties, combined in quadrature.
2) The systematic uncertainty for the final state X which is fully correlated between energy points for that experiment.
3) The systematic uncertainty for experiment Y which is fully correlated between different final states for this energy point.

4) The systematic uncertainty for the final state X which is fully correlated between energy points and between different experiments.

5) The systematic uncertainty which is fully correlated between energy points and between different experiments for all final states.

Note that cross section measurements are always considered to be uncorrelated with asymmetry measurements.

Systematic uncertainties related to detector calibration are always uncorrelated between experiments, and are sometimes also uncorrelated between channels/years. Uncertainties related to a particular Monte Carlo generator, such as the simulation of ISR photons, can be correlated among experiments. The theoretical uncertainty on the luminosity, though small, is an example of something which is fully correlated among all results.

It should be stressed that the breakdown of the errors in this form is a first attempt to do so and that, as such, it should be considered as preliminary.

4 Averaging Method

4.1 Correcting the Input Data

Before they are averaged, the measurements M_{exp} from each experiment must first be corrected to the common choice of signal definition. The correction used is an additive one,

$$M_{\mathrm{common}} = M_{\mathrm{exp}} + (P_{\mathrm{common}} - P_{\mathrm{exp}}),$$

based on the based on the change in the SM prediction P when going from an experiment's own signal definition to the common one. To test the robustness if this procedure, a multiplicative correction

$$M_{\mathrm{common}} = M_{\mathrm{exp}} \times (P_{\mathrm{common}}/P_{\mathrm{exp}})$$

has also been tried and gives almost identical results. (In this case, the uncertainties quoted on each measurement are also scaled by the correction factor.)

The SM predictions are calculated using the semi-analytical program ZFITTER v6.04 [2]. The theoretical uncertainties on these predictions are assessed by comparison with the results of the semi-analytical program TOPAZ0 v4.4 [3] and the Monte Carlo generator KK v4.02 [4]. More details on these, plus other generators used in $\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}}$ analysis, can be found in the web pages of the LEP2 Monte Carlo Workshop [6]. The corrections applied to the data typically correspond to adding/removing ISR-FSR photon interference, changing the definition of $\sqrt{s'}$ between propagator and bare difermion mass, and altering the cuts on $\sqrt{s'}$ or on the polar angle acceptance. The maximum discrepancies seen between ZFITTER, TOPAZ0 and KK for the size of the corrections are 0.2% for the hadronic cross-sections, 0.7% for dilepton cross-sections and 0.003 for the leptonic asymmetries. These are taken as a preliminary estimates of the theoretical uncertainty on the correction procedure [5]. A more exhaustive evaluation of the theoretical uncertainties is currently underway within the framework of the LEP II Generators workshop, a more definitive statement is expected later this year.

4.2 Performing the Average

There are 40 input measurements, comprising 2 centre-of-mass energies times 4 experiments times 3 cross sections plus 2 asymmetries. The 40×40 error matrix E on these measurements is constructed, such that its element i, j is given by

$$E_{ij} = \sum_{k=1}^{5} C_{ij}^{k} \sigma_i^k \sigma_j^k,$$

where the sum extends over the five error contributions described in Section 3. σ_i^k represents the uncertainty on measurement i due to error source k $(1 \leq k \leq 5)$. The factor C_{ij}^k is equal to 1 if error k correlates measurements i and j and equals zero if it does not.

The χ^2 which must be minimized to obtain the averages is then

$$\chi^2 = (\boldsymbol{V} - \boldsymbol{A})^T \ E^{-1} \ (\boldsymbol{V} - \boldsymbol{A}),$$

where $\boldsymbol{V}$ is a vector containing the 40 corrected input measurements, and $\boldsymbol{A}$ is a vector containing the desired averages corresponding to each of these measurements. The 40 elements of vector $\boldsymbol{A}$ consist of ten independent numbers (the averages) repeated four times.

This χ^2 has been minimized both analytically and using a numerical minimization program. The results are identical.

5 Results

In this section the results of the combination made for the 1999 Summer Conferences are presented. This information is also available on the web page [8].

Tables 1a and 1b show the preliminary combined results corresponding to the signal Definitions 1 and 2 respectively, as defined in Section 2. They show the average cross sections and lepton forward-backward asymmetries at 183 and 189 GeV, together with the corresponding SM predictions obtained from ZFITTER v6.04. The quoted uncertainties on each result do not include the theoretical uncertainties arising from correcting the input data to a common signal definition, which are discussed in Section 4.

The χ^2 per degree of freedom of two sets of averages are identical, and equal to 24.6/30. The correlation matrix for the combination is also identical in both cases. It is given Table 2. The correlations are rather small, with the largest being 18% between the $\mathrm{q\bar{q}}$ cross sections at 183 and 189 GeV. The combined errors are dominated by the error component which is the term from the statistical and uncorrelated experimental systematics. For example, for the 189 GeV hadronic cross-section the part of the error arising from the correlated components is about one-third of the total error.

Figures 1 and 2 show the LEP averaged cross sections and asymmetries, respectively, (based on Definition 1), as a function of centre-of-mass energy, together with the SM predictions.

There is good agreement between the SM expectations and the measurements of the individual experiments and the combined averages. There is no evidence in $\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}}$ for physics beyond the SM. The data can be used to put limits on various models of new physics beyond the SM.

cms energy	quantity	average value	SM prediction
183 GeV	$\sigma(\mathrm{q\bar{q}})$	24.54 ± 0.43 pb	24.20 pb
	$\sigma(\mu^+\mu^-)$	3.44 ± 0.14 pb	3.45 pb
	$\sigma(\tau^+\tau^-)$	3.43 ± 0.18 pb	3.45 pb
	$A_{\mathrm{FB}}(\mu^+\mu^-)$	0.547 ± 0.034	0.576
	$A_{\mathrm{FB}}(\tau^+\tau^-)$	0.615 ± 0.044	0.576
189 GeV	$\sigma(\mathrm{q\bar{q}})$	22.38 ± 0.25 pb	22.16 pb
	$\sigma(\mu^+\mu^-)$	3.193 ± 0.083 pb	3.207 pb
	$\sigma(\tau^+\tau^-)$	3.135 ± 0.102 pb	3.207 pb
	$A_{\mathrm{FB}}(\mu^+\mu^-)$	0.562 ± 0.022	0.569
	$A_{\mathrm{FB}}(\tau^+\tau^-)$	0.597 ± 0.027	0.569

Table 1a: *Preliminary combined 183 and 189 GeV LEP results for* $\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}}$*. The results all correspond to the signal Definition 1 described in Section 2. The quoted uncertainties do not include the theoretical uncertainties discussed in section 4.*

cms energy	quantity	average value	SM prediction
183 GeV	$\sigma(\mathrm{q\bar{q}})$	24.43 ± 0.43 pb	24.09 pb
	$\sigma(\mu^+\mu^-)$	3.30 ± 0.14 pb	3.31 pb
	$\sigma(\tau^+\tau^-)$	3.38 ± 0.18 pb	3.40 pb
	$A_{\mathrm{FB}}(\mu^+\mu^-)$	0.565 ± 0.034	0.594
	$A_{\mathrm{FB}}(\tau^+\tau^-)$	0.633 ± 0.044	0.594
189 GeV	$\sigma(\mathrm{q\bar{q}})$	22.28 ± 0.25 pb	22.06 pb
	$\sigma(\mu^+\mu^-)$	3.062 ± 0.083 pb	3.076 pb
	$\sigma(\tau^+\tau^-)$	3.087 ± 0.102 pb	3.159 pb
	$A_{\mathrm{FB}}(\mu^+\mu^-)$	0.581 ± 0.022	0.588
	$A_{\mathrm{FB}}(\tau^+\tau^-)$	0.615 ± 0.027	0.587

Table 1b: *Preliminary combined 183 and 189 GeV LEP results for* $\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}}$*. The results all correspond to the signal Definition 2 described in Section 2. The quoted uncertainties do not include the theoretical uncertainties discussed in section 4.*

cms energy	quantity										
183 GeV	$\sigma(\mathrm{q\bar{q}})$	1.00	0.01	0.02	0.00	0.00	0.18	0.01	0.01	0.00	0.00
	$\sigma(\mu^+\mu^-)$	0.01	1.00	0.01	0.00	0.00	0.01	0.08	0.00	0.00	0.00
	$\sigma(\tau^+\tau^-)$	0.02	0.01	1.00	0.00	0.00	0.01	0.00	0.09	0.00	0.00
	$A_{\mathrm{FB}}(\mu^+\mu^-)$	0.00	0.00	0.00	1.00	0.01	0.00	0.00	0.00	0.04	0.00
	$A_{\mathrm{FB}}(\tau^+\tau^-)$	0.00	0.00	0.00	0.01	1.00	0.00	0.00	0.00	0.00	0.03
189 GeV	$\sigma(\mathrm{q\bar{q}})$	0.18	0.01	0.01	0.00	0.00	1.00	0.01	0.01	0.00	0.00
	$\sigma(\mu^+\mu^-)$	0.01	0.08	0.00	0.00	0.00	0.01	1.00	0.00	0.00	0.00
	$\sigma(\tau^+\tau^-)$	0.01	0.00	0.09	0.00	0.00	0.01	0.00	1.00	0.00	0.00
	$A_{\mathrm{FB}}(\mu^+\mu^-)$	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	1.00	0.04
	$A_{\mathrm{FB}}(\tau^+\tau^-)$	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.04	1.00

Table 2: *The correlation matrix of the averaged results.*

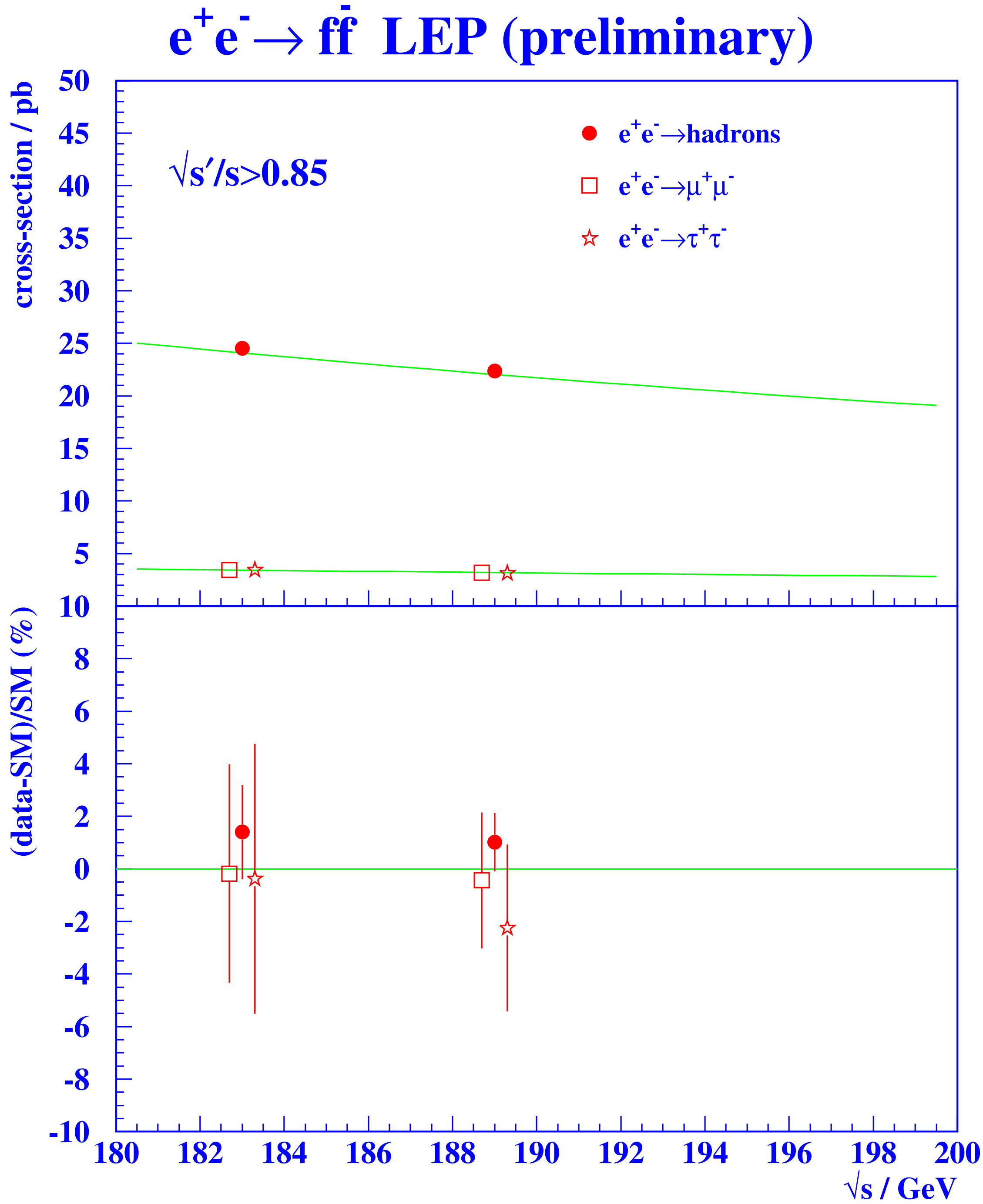

Figure 1: *Preliminary combined LEP results on the cross sections for* $\mathrm{q\bar{q}}$, $\mu^+\mu^-$ *and* $\tau^+\tau^-$ *final states, as a function of cms energy. The expectations of the SM are also shown. The lower plot shows differences between the data and the SM, divided by the SM prediction.*

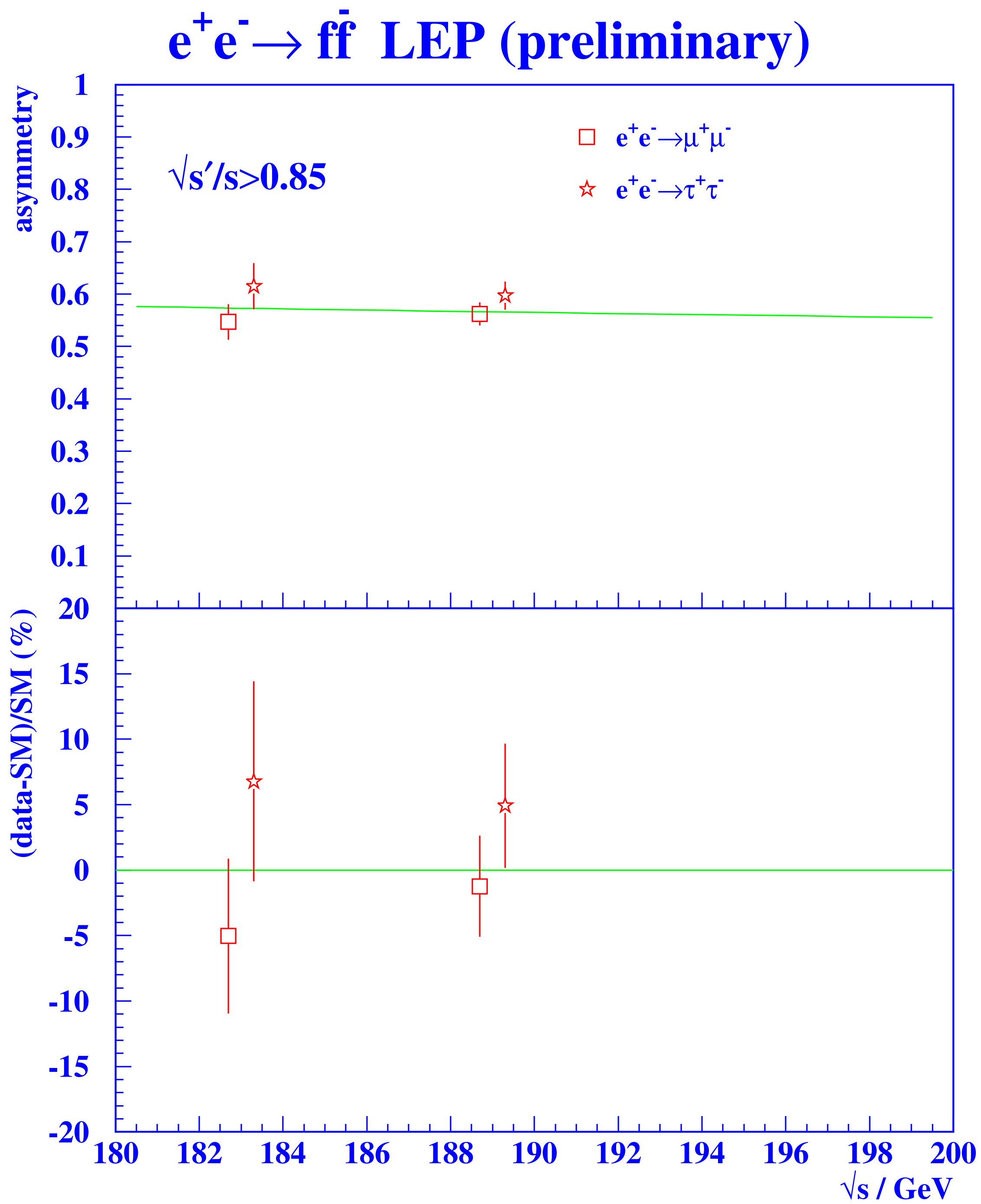

Figure 2: *Preliminary combined LEP results on the forward-backward asymmetry for $\mu^+\mu^-$ and $\tau^+\tau^-$ final states as a function of cms energy. The expectations of the SM are also shown. The lower plot shows differences between the data and the SM, divided by the SM prediction.*

6 Contact Interactions

As an example of the sensitivity to physics beyond the Standard Models of the combined results, compared to the results of a single experiment, the combined cross-sections and asymmetries for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ have been used to place limits on contact interactions between leptons. Following reference [9] these interactions are parameterised by an effective Lagrangian, $\mathcal{L}_{eff}$, added to the Standard Model Lagrangian of the form:

$$\mathcal{L}_{eff} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} \overline{e}_i \gamma_\mu e_i \overline{f}_j \gamma^\mu f_j,$$

where $g^2/4\pi$ is taken to be 1 by convention, $\delta = 1(0)$ for $f = e(f \neq e)$, $\eta_{ij} = \pm 1$ or 0, Λ is the scale of the contact interactions, e_i and f_j are left or right-handed spinors. By assuming different helicity coupling between the initial state and final state currents and either constructive or destructive interference with the Standard Model (according to the choice of each η_{ij}) a basic set of 6 different models can be defined from this Lagrangian [10], with either constructive (+) or destructive (−) interference between the Standard Model process and the contact interactions. The models LL, RR, VV and AA are considered here since these models lead to large deviations in the $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ channels. The total hadronic cross-section on its own is not particularly sensitive to contact interactions involving quarks. For the purpose of fitting contact interaction models to the data, a new parameter $\epsilon = 1/\Lambda^2$ is defined; with $\epsilon = 0$ in the limit that there are no contact interactions. This parameter is allowed to take both positive and negative values in the fits. The values of ϵ extracted for each model were all compatible with the Standard Model expectation $\epsilon = 0$, at the two standard deviation level. These errors on ϵ are typically a factor of two smaller than those obtained from a single LEP experiment with the same data set. The fitted values of ϵ were converted into 95% confidence level lower limits on Λ, and are shown in Table 3. The limits obtained are not particularly sensitive to the method used to extract the limits. Figure 3 shows the limits obtained on the scale Λ for the different models assuming universality between contact interactions for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$.

7 Summary and Future Work

A preliminary combination of the LEP2 $\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}}$ results for the 183 and 189 GeV data sets has been made. The results from the four LEP experiments are in good agreement with each other. Furthermore, the combined $\mathrm{q\bar{q}}$, $\mu^+\mu^-$ and $\tau^+\tau^-$ cross sections and the $\mu^+\mu^-$ and $\tau^+\tau^-$ asymmetries are consistent with SM expectations.

In the future it is planned to consider the inclusion of the lower energy data sets as well as to include the data taken in 1999-2000. Hopefully, other results such as those on Bhabha and heavy quark production can also be combined. The breakdown of the systematic errors into the various components of correlation categories should also be addressed again. It is also foreseen to use the LEP averages to place limits on various models of physics beyond the SM. In some of these models, the extrapolations to 4π used here are not strictly valid, as the expected angular distributions in these models are different to those of the SM. This could be circumvented either by giving experimental details on the angular acceptance of the various experiments or by combining differential cross sections as a function of polar angle.

$e^+e^- \to \mu^+\mu^-$			
Model	$\epsilon^{+\sigma_+}_{-\sigma_-}$ (TeV^{-2})	Λ^+(TeV)	Λ^-(TeV)
LL	$-0.001^{+0.008}_{-0.008}$	8.8	8.4
RR	$-0.002^{+0.009}_{-0.009}$	8.4	8.0
VV	$0.000^{+0.003}_{-0.003}$	14.0	14.4
AA	$-0.002^{+0.004}_{-0.004}$	12.0	10.6

$e^+e^- \to \tau^+\tau^-$			
Model	$\epsilon^{+\sigma_+}_{-\sigma_-}$ (TeV^{-2})	Λ^+(TeV)	Λ^-(TeV)
LL	$-0.002^{+0.009}_{-0.010}$	7.9	7.3
RR	$-0.002^{+0.010}_{-0.011}$	7.5	7.0
VV	$-0.003^{+0.004}_{-0.004}$	12.7	10.3
AA	$0.004^{+0.005}_{-0.005}$	9.1	10.9

$e^+e^- \to l^+l^-$			
Model	$\epsilon^{+\sigma_+}_{-\sigma_-}$ (TeV^{-2})	Λ^+(TeV)	Λ^-(TeV)
LL	$-0.003^{+0.006}_{-0.006}$	10.0	8.8
RR	$-0.003^{+0.007}_{-0.007}$	9.5	8.4
VV	$-0.002^{+0.002}_{-0.002}$	16.2	14.0
AA	$0.000^{+0.003}_{-0.003}$	13.6	13.2

Table 3: Fitted values of ϵ and 95% confidence limits on the scale, Λ, for constructive (+) and destructive interference ($-$) with the Standard Model, for the contact interaction models discussed in the text. Results are given for $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \tau^+\tau^-$ and $e^+e^- \to l^+l^-$, assuming universality in the contact interactions between $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \tau^+\tau^-$.

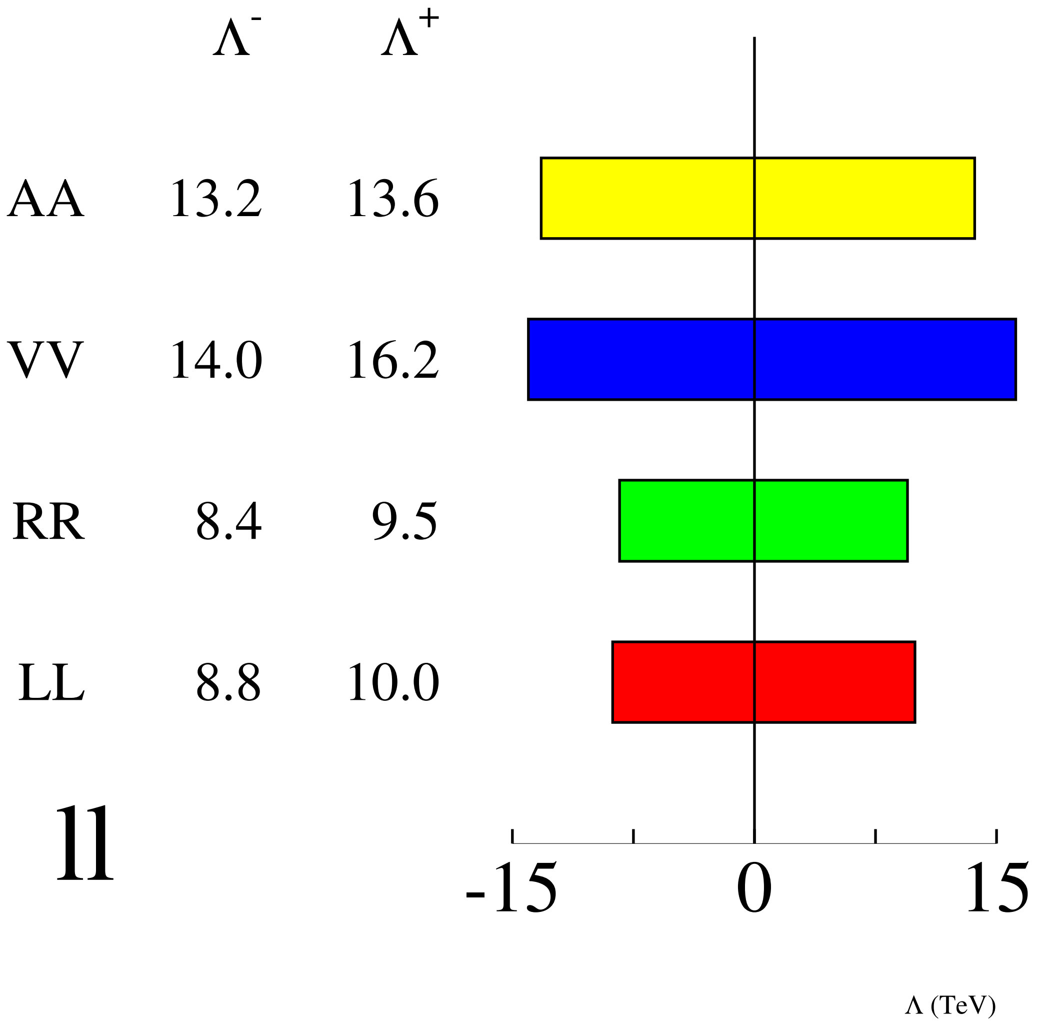

Figure 3: The limits on Λ for $e^+e^- \to l^+l^-$ assuming universality in the contact interactions between $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \tau^+\tau^-$.

Acknowledgements

The analysis and interpretation of the high energy $f\bar{f}$ data requires the theoretical input from Monte Carlo programs to compute efficiencies, from programs to compute the luminosity and programs which make Standard Model predictions. We would like to acknowledge the work of all the authors of these programs. In particular we are grateful to D. Bardin, S. Jadach, and G. Passarino for their many and direct contributions to our work.

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DELPHI Collab., *"Results on Fermion-Pair Production at LEP running near 183 and 189 GeV"*, DELPHI-MORIO-CONF-247, contribution #6_362 to EPS-HEP conference, Tampere, Finland (1999);
L3 Collab., *"Measurement of Hadron and Lepton-Pair Production above the Z resonance"*, L3 note 2398, contribution #6_262 to EPS-HEP conference, Tampere, Finland (1999);
OPAL Collab., *"Tests of the Standard Model and Constraints on New Physics from Measurements of Fermion Pair Production at 183 GeV at LEP"*, Euro. Phys. J. **C6** (1999) 1; *"Tests of the Standard Model and Constraints on New Physics from Measurements of Fermion Pair Production at LEP2"*, contribution #20 to EPS-HEP conference, Tampere, Finland (1999).

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Appendix: Experimental input

Aleph 183

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* Results published in CERN-EP/99-042 (submitted to Euro. Phys. J. C).
*
* Results are for sqrt(s'/s)>0.9 and abs(cos(theta))< 0.95,
* where s' is the mass squared of the dilepton pair for leptonic events
* or of the s-channel propagator for hadronic events, with no ISR/FSR
* interference subtraction. theta is the polar angle of the fermion.
*
* ZFITTER flags used: INTF=1; ISPP=0; FINR=0 for hadrons, FINR=1 for leptons.
*        input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                          alpha_qed=1/128.878, alpha_s=0.119
*
* Exact centre-of-mass energy: 182.7 GeV
*
*           Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*            v6.04    -ment    Error  between  between   between  between
*                                      years   channels   years    every
*                                                        & exper.  thing
*
XSEC_QQ      21.24    21.71    0.71    0.16      0.12      0.09     0.06
XSEC_MUMU     2.871    2.98    0.25    0.045     0.004     0.019    0.012
XSEC_TAUTAU   2.974    2.90    0.292   0.048     0.067     0.011    0.012
AFB_MUMU      0.579    0.54    0.06    0.02      0.01      0.004    0.0
AFB_TAUTAU    0.579    0.52    0.08    0.03      0.02      0.004    0.0
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Aleph 189

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* Preliminary results published in ALEPH-CONF/99-013 (La Thuile 99 conf.)
*
* Results are for sqrt(s'/s)>0.9 and abs(cos(theta))< 0.95,
* where s' is the mass squared of the dilepton pair for leptonic events
* or of the s-channel propagator for hadronic events, with no ISR/FSR
* interference subtraction. theta is the polar angle of the fermion.
*
* ZFITTER flags used: INTF=1; ISPP=0; FINR=0 for hadrons, FINR=1 for leptons.
*        input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                          alpha_qed=1/128.878, alpha_s=0.119
*
* Exact centre-of-mass energy: 188.6 GeV
*
*           Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*            v6.04    -ment    Error  between  between   between  between
*                                      years   channels   years    every
*                                                        & exper.  thing
*
XSEC_QQ      19.45    19.57    0.44    0.10      0.06      0.07     0.03
XSEC_MUMU     2.670    2.66    0.133   0.043     0.006     0.017    0.003
XSEC_TAUTAU   2.765    2.39    0.152   0.045     0.008     0.011    0.003
AFB_MUMU      0.573    0.581   0.037   0.002     0.01      0.004    0.0
AFB_TAUTAU    0.572    0.569   0.051   0.012     0.04      0.004    0.0
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Delphi 183

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* Preliminary Results published in: DELPHI 99-58 MORIO CONF 247
*
* Measurement are corrected compared to published results to include
* interference in the extrapolation for leptons and for s' definition
* for hadrons. Results are for sqrt(s'/s)>0.85. They are extrapolated
* to 4 pi acceptance. No subtraction for initial-final state interference.
*
* ZFITTER flags used; FINR = 1 ; INTF = 1 ; SIPP cut = s*(0.85)^2
*         input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                           alpha_qed=1/128.878, alpha_s=0.119
*
* Centre-of-mass energy used: 182.7 GeV
*
*           Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*            v6.04    -ment    Error  between  between   between  between
*                                      years   channels   years    every
*                                                        & exper.  thing
*
XSEC_QQ       23.76    26.4     1.09   0.28      0.13      0.066    0.066
XSEC_MUMU      3.320   3.31     0.28   0.07      0.017     0.008    0.008
XSEC_TAUTAU    3.403    3.60    0.43   0.06      0.016     0.008    0.008
AFB_MUMU       0.594    0.565   0.068  0.010     0.0       0.001    0.0
AFB_TAUTAU     0.593    0.682   0.087  0.007     0.0       0.002    0.0
```

Delphi 189

```
* Preliminary Results published in: DELPHI 99-58 MORIO CONF 247
*
* Measurement are corrected compared to published results to include
* interference in the extrapolation for leptons and for s' definition
* for hadrons. Results are for sqrt(s'/s)>0.85. They are extrapolated
* to 4 pi acceptance. No subtraction for initial-final state interference.
*
* ZFITTER flags used; FINR = 1 ; INTF = 1 ; SIPP cut = s*(0.85)^2
*         input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                           alpha_qed=1/128.878, alpha_s=0.119
*
* Centre-of-mass energy used: 188.7 GeV
*
*           Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*            v6.04    -ment    Error  between  between   between  between
*                                      years   channels   years    every
*                                                        & exper.  thing
*
XSEC_QQ       21.72    21.8     0.53   0.28      0.10      0.055    0.055
XSEC_MUMU      3.086    3.03    0.18   0.07      0.015     0.008    0.008
XSEC_TAUTAU    3.164    3.23    0.26   0.05      0.016     0.008    0.008
AFB_MUMU       0.588    0.585   0.044  0.010     0.0       0.001    0.0
AFB_TAUTAU     0.587    0.687   0.053  0.007     0.0       0.002    0.0
```

L3 183

```
* Results published in L3 note 2398 for EPS99 /PRELIMINARY/
*
* Results are for s'/s>0.7225. They are for the full solid angle,
* have been corrected to no interference between initial- and final-
* state radiation.
*
* ZFITTER flags used: FINR=0, INTF=0; SIPP cut = 0.7225*Ecm**2
*         input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                           alpha_qed=1/128.878, alpha_s=0.119
*
* Exact centre-of-mass energy: 182.68 GeV
*
*            Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*             v6.04    -ment    Error  between  between   between  between
*                                       years   channels   years    every
*                                                         & exper.  thing
*
XSEC_QQ       24.20    24.2     0.8     0.30      0.05      0.03     0.03
XSEC_MUMU      3.446    3.25    0.31    0.085     0.006     0.012    0.004
XSEC_TAUTAU    3.446    3.7     0.4     0.105     0.006     0.010    0.004
AFB_MUMU       0.576    0.56    0.07    0.010     0.0       0.004    0.0
AFB_TAUTAU     0.576    0.59    0.09    0.010     0.0       0.004    0.0
```

L3 189

```
* Results published in L3 note 2398 for EPS99 /PRELIMINARY/
*
* Results are for s'/s>0.7225. They are for the full solid angle,
* have been corrected to no interference between initial- and final-
* state radiation.
*
* ZFITTER flags used: FINR=0, INTF=0; SIPP cut = 0.7225*Ecm**2
*         input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                           alpha_qed=1/128.878, alpha_s=0.119
*
* Exact centre-of-mass energy: 188.6  GeV
*
*            Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*             v6.04    -ment    Error  between  between   between  between
*                                       years   channels   years    every
*                                                         & exper.  thing
*
XSEC_QQ       22.16    22.8     0.4     0.21      0.05      0.03     0.03
XSEC_MUMU      3.207    3.38    0.19    0.070     0.006     0.012    0.004
XSEC_TAUTAU    3.207    3.14    0.21    0.095     0.006     0.010    0.004
AFB_MUMU       0.569    0.566   0.045   0.010     0.0       0.004    0.0
AFB_TAUTAU     0.569    0.533   0.053   0.010     0.0       0.004    0.0
```

Opal 183

```
* Results published in Eur. Phys. J. C6 (1999) 1.
*
* Results are for s'/s>0.7225. They are for the full solid angle,
* have been corrected to no interference between initial- and final-
* state radiation, and the four-fermion contribution treated as
* described in Eur. Phys. J. C2 (1998) 441.
*
* The hadronic cross section has been updated from the published value
* to correct the overestimate of the interference correction using
* ZFITTER5.0.
*
* ZFITTER flags used: FINR=0, INTF=0; SIPP cut = 0.7225*Ecm**2
*         input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                           alpha_qed=1/128.878, alpha_s=0.119
*
* Exact centre-of-mass energy: 182.69 GeV
*
*           Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*            v6.04    -ment    Error  between  between   between  between
*                                      years   channels   years    every
*                                                        & exper.  thing
*
XSEC_QQ      24.20    23.50    0.72    0.38      0.08      0.05     0.06
XSEC_MUMU     3.446    3.463   0.284   0.045     0.012     0.013    0.009
XSEC_TAUTAU   3.446    3.315   0.302   0.103     0.012     0.011    0.008
AFB_MUMU      0.576    0.543   0.071   0.011     0.0       0.004    0.0
AFB_TAUTAU    0.576    0.683   0.088   0.002     0.0       0.004    0.0
```

Opal 189

```
* Preliminary Results
*
* Results are for s'/s>0.7225. They are for the full solid angle,
* have been corrected to no interference between initial- and final-
* state radiation, and the four-fermion contribution treated as
* described in Eur. Phys. J. C2 (1998) 441.
*
* ZFITTER flags used: FINR=0, INTF=0; SIPP cut = 0.7225*Ecm**2
*         input parameters: mZ=91.1867, mt=171.1, mH=127.0,
*                           alpha_qed=1/128.878, alpha_s=0.119
*
* Exact centre-of-mass energy: 188.63 GeV
*
*           Zfitter  Measure  Uncorr  -------------- Corr-error ---------
*            v6.04    -ment    Error  between  between   between  between
*                                      years   channels   years    every
*                                                        & exper.  thing
*
XSEC_QQ      22.16    22.10    0.37    0.22      0.04      0.05     0.03
XSEC_MUMU     3.207    3.111   0.140   0.045     0.006     0.012    0.004
XSEC_TAUTAU   3.207    3.539   0.176   0.104     0.006     0.010    0.004
AFB_MUMU      0.569    0.532   0.042   0.007     0.0       0.004    0.0
AFB_TAUTAU    0.569    0.606   0.048   0.007     0.0       0.003    0.0
```